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Further Notes on United Kingdom Research of Techniques for Distinguishing Between Earthquakes and Underground Explosions

1. In September 1965, research by United Kingdom scientists on techniques for distinguishing between earthquakes and underground explosions was described to the E.N.D.C. (ENDC/155). This early work had led in 1962 to the concept of monitoring by means of some 20 to 25 control stations external to the country conducting tests: this number compared with 180 stations proposed by the Geneva Conference of Experts*. The system considered depended on the use of large arrays deployed on carefully chosen low noise sites, recording on magnetic tape, and electrical and machine processing to further enhance the clarity of the signals. The conclusion reached in ENDC/155 was that, in spite of the technical advances which had been made, there would remain a number of detected seismic events greater than magnitude 4.0 which would not be identified by remote seismic means alone and which could be suspected as possible violations of a test ban, unless they could be eliminated by some supplementary means such as on-site inspection.

2. In December of the same year (1965) the United Kingdom Atomic Energy Authority (U.K.A.E.A.) published a Special Report which reviewed the discussions and outstanding problems of Technical Working Group 2 (which had been set up in Geneva to re-examine the facts relating to underground explosions), the early U.K. work on discrimination assuming the use of a network of the type envisaged by the Geneva Conference of Experts, and the results of investigations (briefly described in ENDC/155) into the possibilities of using control stations spaced at much greater distances than was envisaged by the Geneva experts. The studies described confirmed the hypothesis that seismic signals recorded at distances between 3,000 km - 10,000 km from the source of explosion and earthquakes were much less disturbed by signals trapped in the complex transmission paths formed by the crustal skin of the earth than those recorded nearer the source; information about the source could therefore be extracted with greater clarity and interpreted with greater confidence.

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* (U.N. Publication A/3897, August 28 1958)

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3. In particular, the U.K.A.E.A. reported comparisons between earthquakes and 35 underground explosions fired at 8 different locations in the U.S.S.R., U.S.A. and North Africa. It was shown that the first group of seismic signals which arrive at a distant station (the P-wave train) could be used to identify 90% of the annual total of earthquakes down to magnitude 4.0 and to distinguish them from explosions in those regions, using three criteria. These were first motion, depth of focus and complexity, the last being the most useful. However, shortly before the report was published, another test was carried out at a new underground site. This explosion radiated signals typical of explosions to Europe, but signals typical of earthquakes to North America. Doubt was thereby cast on the usefulness of the complexity criterion. U.K. scientists are still investigating this unusual effect, and have narrowed the possible causes to the source region, and almost certainly to the effect of rugged topography on the siesmic signals spreading round the source. It is analogous to the effect of rugged topography around a receiving station, which results in signal-generated noise.

4. It is to be noted especially that the U.K.A.E.A. special report referred only to identifying earthquakes since at the time of its publication there was no established method for identifying explosions. Events were classified either as earthquakes or as unidentified events. The U.K.A.E.A. report did however refer to some observations which appeared to confirm some theoretical studies (presented by U.K. scientists at an international conference in Beaugency, France in October 1964) which predicted that explosions were much less efficient than earthquakes at generating Rayleigh surface waves (R-waves).

5. This observation offered some hope that a good criterion for identifying explosions might be developed but was not given prominence because R-waves were not well recorded by the long period equipment deployed at that time, and because it was still uncertain whether a useful detection threshold for R-waves from explosions could be achieved. Since then, however, many more observations have accumulated, which bear out the suggested relationship. In all but a very few cases the magnitude of an explosion as measured by R-waves is approximately one unit (a factor of 10) less than its magnitude as measured by P-waves. For earthquakes the magnitude determined from the observation of these two waves are the same.

6. Techniques and instrumentation for observing R-waves have been enormously improved in recent years and this method of distinguishing between earthquakes and explosions is now well established. It is the only one which enables explosions to be identified as such.

7. In 1966, U.K. scientists used the World Wide Standard Seismological Network (WWSSN) and the 4 U.K. arrays to test the surface wave, and the other three criteria, on events which occurred in that year in the Sino-Soviet region of Asia. It was also a useful test of the capability of the 120-station network, which was established on the initiative of the Vela Uniform Programme of the United States of America. These stations have a world wide distribution except for the Sino-Soviet region and transmit the arrival times of seismic signals to the United States Coast and Geodetic Survey (U.S.C.G.S.) data centre in Washington which calculates epicentre locations. The data centre also provides low cost microfilm copies of the original records. (These records were delayed up to two months, depending on the timing of routine despatches by individual stations to the data centre). With the exception of the 4 arrays the stations were all equipped with standard six component seismometers recording on photographic paper. Only the short period and long period vertical components were used in the investigations.

8. A total of 245 events were detected in the region studied, and the threshold at which 90% of the events were detected lay between m_b 4.5 and m_b 4.75 (where m_b is the magnitude of the event as determined from the P-wave train). Surface waves were recorded from 214 of the 245 events. In 9 of these 214 results m_b was greater than m_s by an order of magnitude and they were located at a known test site. (m_s is the magnitude of the event determined from the R-wave component). They could therefore be confidently identified as explosions. All but 10 of the remaining 31 events were identified as earthquakes, using the other three criteria. 10 events remain unidentified, and the magnitude of 8 of them lie below the threshold for 95% confidence in detection. Of the other two one appeared to have been located at a known test site and may therefore have been an explosion.

9. In this study the detection threshold of the W.W.S.S.N. for earthquake R-waves was similar to that for P-waves, as would be expected. On the other hand, for explosions, the detection threshold for R-waves corresponded to an event which gave m_b equal to 5.25.

10. These results were presented to the study group on seismic methods for monitoring underground explosions organized by the International Peace Research Institute, Stockholm (SIPRI). They were the principal data on which the group concluded that the national systems which are operational at the present time could detect and identify explosions in the Northern Hemisphere down to a level of 20 - 60 kilotons. On the basis of research presented by Canada, the U.S.A. and the U.K., the group further concluded that the R-wave criterion was valid down to m_b 4.5. This was tacitly accepted by the group to be the equivalent of about 10 kt. There is not however complete technical agreement about the exact hard rock magnitude-yield equivalence and the discussions are without doubt confused by differences in regional geology.

11. The study group also concluded that it is possible to reduce by a factor of 10 the amplitude of the P-signal by conducting explosions in a suitable thickness of dry alluvium. It was agreed that dry alluvium is present in most continents in thicknesses sufficient to decouple up to 20 kt, that is to reduce an event in hard rock of m_b 5 to one of m_b 4. Since m_b 4 is close to the ultimate detection threshold of a practical control system, it is difficult to see how it will be possible to achieve a high probability of seismically locating a 10 kt explosion which is fired in dry alluvium at distances greater than two or three thousand km, let alone to identify it by means of its R-waves.

12. The SIPRI study group therefore made two significant advances in terms of scientific agreement: it agreed that explosions of yields down to 10 kt in hard rock could be identified (given the deployment of a seismic system incorporating the improvements suggested in the SIPRI report) and it agreed that seismic amplitudes from explosions of up to 20 kt could be reduced by a factor of ten by firing in dry alluvium. The United Kingdom conclude that seismological verification of a test ban over large areas is limited to yields of about 10 kt and over: and even this capability assumes that modern equipment replaces that of the standard stations. Improving the instrumentation of the existing network may, however, be uneconomical or insufficient to do more than fully realize the limited capabilities recognized by the SIPRI group: to lower the identification threshold (and there are already some studies which indicate that this can be achieved) it may be necessary to consider new systems. Stations using new techniques are listed in table 1.1 of the SIPRI report and their capabilities habe been described in a large number of reports. The next step may be a detailed study of the ways and means of deploying an operational system based on the new techniques.

ANNEX

ANNEXE

ПРИЛОЖЕНИЕ

ANEXO

PUBLICATIONS ON DETECTION GEOPHYSICS BY SCIENTISTS OF THE UK ATOMIC ENERGY AUTHORITY AND OTHERS

PUBLICATIONS TRAITANT DE LA GEOPHYSIQUE DE DETECTION DUES AUX SAVANTS DE LA UNITED KINGDOM ATOMIC ENERGY AUTHORITY OU D'AUTRES

ПУБЛИКАЦИИ УЧЕНЫХ УПРАВЛЕНИЯ ПО АТОМНОЙ ЭНЕРГИИ СОЕДИНЕННОГО КОРОЛЕВСТВА И ДРУГИХ СТРАН ПО ГЕОФИЗИКЕ ОБНАРУЖЕНИЯ

PUBLICACIONES SOBRE GEOFISICA APLICADA A LA DETECCION, DE LAS QUE SON AUTORES CIENTIFICOS DE LA U.K. ATOMIC ENERGY AUTHORITY Y OTROS HOMBRES DE CIENCIA

A. Review papers

A. Articles de synthèse

А. Обзорные доклады

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B. Papers on specific Topics

B. Articles spécialisés

В. Доклады по специальным темам

B. Monografías

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